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THE INDIAN WHEAT RUST PROBLEM.

Part I

By E. J. BUTLER, M.B., F.L.S., *Cryptogamic Botanist to the Government of India.*

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THE
INDIAN WHEAT RUST PROBLEM.

The most important of fungus diseases.

1. The rusts of Indian cereals form the most important of the many diseases due to the attacks of parasitic fungi which damage the crops of this country. Not only on account of the actual loss annually produced, but also because of the importance of the grain as an article of food, no other diseases approach in their consequences to these.

Their neglect.

2. Writing in 1892, the late **Dr. Barclay**, who devoted many years of his life to the group of fungi to which the rusts belong, said: "It is astonishing how little attention has been paid in India to this source, sometimes of enormous loss, and always, as appears probable, of considerable loss." Since that time, however, the subject has come gradually into prominence, and two important papers dealing with it have appeared. One of these, published in 1896, by **Doctors Cunningham** and **Prain** at Calcutta, contained the results of investigations which they had carried out in that year on the distribution of the various rusts in Northern India, and the characters of the several fungi concerned. The other, written in 1897 by **Dr. Prain** at the instance of the Government of India, gave a summary of the work done up to that date in the Australian colonies where the rust in wheat question has attracted great and wide-spread attention, together with a *resumé* of the state of the rust problem at that time, translated from the German of **Dr. Eriksson.**

Some previous work.

Need for special study in India.

3. Both of these papers showed the need which existed for systematic and patient research before even the foundations of a rational knowledge of the rust question could be laid, much less the lines of treatment indicated. For there was no one point brought forward more clearly than that the problem requires to be approached afresh in India, and cannot be dealt with from the standpoint of work accomplished elsewhere; a truism which is now recognised wherever the subject has attracted attention, that is, practically wherever wheat is grown. The conditions in one area are often so different from those which prevail in another, that the conclusions drawn from the one are to a great extent useless when applied to the other. Besides, even where the trained energies of many observers have been directed continuously for years to the one problem, as in Sweden and some other European countries, and in

Australia, the solution is still far from being in view. Indeed there are few diseases of plants so obscure as this, and its difficulties instead of diminishing appear to increase with each succeeding advance of knowledge.

Need for co-operation.

4. There is, then, in India the greatest need for information of a sort which can only be gained by patient and accurate observation carried on at many localities during the few months of each year when rust makes its appearance; and this note has been prepared in the hope of exciting the interest of those whose opportunities permit them to join in the work.

The Magnitude of the Interests Involved.

Estimates of annual loss in India.

5. Dr. Barclay, in an attempt to estimate the annual loss from the rust of wheat in India, took, as a standard of comparison, one of the lowest estimates which has been made in any considerable wheat-growing country, namely, that of one per cent. of the yield made by Mr. L. H. Bolley of the Indiana Agricultural Experiment Station, in the United States. On this basis he considered that the least loss occasioned by rust in India may be set down with comparative certainty at R40,00,000 annually, supposing that rust prevails throughout the wheat-producing areas of India. Sir George Watt held this figure to be much too low, and that the annual loss is very probably not far short of ten times as much, or ten per cent. of the yield. And this is probably nearer the correct figure. From the estimates of the Prussian Statistics Bureau in 1891, the loss in that year in the Prussian wheat harvest reached 31 per cent. This was a very bad year, but the annual loss probably exceeds ten per cent. in Prussia. In Australia the loss is considered to be from £2,000,000 to £3,000,000 per annum. In England in 1892, in answer to a circular from the Board of Agriculture, a number of farmers estimated their losses at from 9 to 16 bushels an acre, though that the average was considerably lower than this over the whole country is apparent from the fact that on 9 out of 37 of those farms from which answers were received no attack of rust was observed.

6. It is only by actual weighing of the produce of diseased against healthy plots that any accurate estimate can be formed, since the loss is often far greater than appears on the surface. Dr. Barclay, indeed, showed that the effects of the parasite were strikingly apparent when grain from a diseased ear was weighed against that from a healthy plant. As an average of several weighings he found that 10 healthy grains weighed as much as 30 diseased ones when the parasite was **Puccinia graminis**, and as 60 diseased grains when the parasite was **Puccinia "rubigo-vera."** The loss here in individual plants reached the enormous total of 200 and 500 per cent., according to the variety of rust present.

7. The fact that it is by no means rare in India to see the ground red under the stalks through field after field, from the shedding of the uredospores of the fungus, shows to what an immense figure the damage must mount from this loss of weight, since it means that where this appearance is noticed, scarcely a plant is free from the disease.

8. Probably, then, ₹4,00,00,000 is not above the annual loss to India from this source.

The Area Affected.

Probably every wheat district in India affected.

9. Probably every district where wheat is grown in India suffers more or less severely from the disease. I have this year either personally seen rust on wheat, or obtained specimens of it, from the following districts: *Bengal*, Dumraon; *United Provinces*, Cawnpore, Dehra Dun; *Panjab*, Hissar, Lyallpur; *Bombay*, Poona; *Central Provinces*, Nagpur; so that it is safe to say that all Northern and Central India is affected. It was a year, too, when rust was not much in evidence and which gave a bumper crop over almost the whole country.

The Nature of the Disease.

Characters of the *Uredineæ* and especially of those on wheat.

10. The rusts belong to a group of parasitic fungi, the **Uredineæ**, which are remarkable for possessing, when perfectly developed, four distinct phases in the life-history. These are characterized by four distinct forms, which, though belonging to the one plant, are often separated from one another by an interval of time, and sometimes require more than one host-plant for their successive development.

11. To fully understand the problem presented by the disease it is necessary that a brief account should be given of these four phases.

12. The first stage in the life-history of one of the wheat rusts may be taken as marked by the first appearance of rust-pustules on the growing wheat, an event which, in Northern India, usually happens in January or February. When a piece of wheat plant showing the first evidences of rusting is examined, it is found to be marked here and there by round, oval, or elongated raised patches of a reddish colour known as sori. The fungus has existed, however, within the tissues of the plant for some time before the appearance of the sori, which are, in a sense, comparable to the fruit-capsules of higher plants. The fungus plant itself is composed of a ramifying body of threads occupying the spaces between the cells of the leaf or stalk, and consuming the nourishment which, under ordinary circumstances, should go to feed these. When its development has reached a certain stage it bursts to the surface to form the sori. The particular position which these sori occupy differs to some extent in the different rusts. They are sometimes practically confined to the leaves, sometimes are found on the leaf-sheaths, culms, and even the ears as well. Each

of them results from an accumulation of fungus-threads beneath the epidermis, which at first covers the sorus and prevents the contents from being seen. Later on the epidermis ruptures and exposes to view a yellow dust, consisting of thousands of spores, which have been formed from the tips of the threads at the bottom of the sorus. These are the uredospores. Their production occurs in myriads, and it is as a result of their shedding, after the rupture of the sori, that the ground under the wheat, in bad years of the disease, takes on its reddish colour.

Uredospores.

13. The uredospore is a single-celled body with a double wall, provided with fine spines or teeth admirably suited for anchoring it to the object on which it has fallen. Its function is the rapid dissemination of the disease from plant to plant, by the agency of the wind. The wall is not of uniform thickness all the way round, but is provided with a certain number of thinnings or "pores" through which the germ-filaments push when the spore germinates. For the latter, all that is necessary is that the spore should, when ripe, fall into water or on to the surface of a plant moistened by rain or dew. That this is often the case, and that the plant is probably a wheat plant is natural, considering the manner in which wheat habitually covers large areas continuously.

14. The germ-filament secures the further propagation of the fungus only when it encounters in its growth one of the stomata or air-pores of the wheat plant; otherwise it breaks up and dies rapidly. Having entered the stoma it ramifies through the substance of the plant, forming what is known as a "mycelium," or branched body of threads, between and around the cells, exactly like that which preceded the first appearance of the sori. From this mycelium fresh uredo-sori may be produced or the fungus may enter on its second stage of development, the Teleuto-stage.

Teleuto-spores.

15. The Teleuto-stage is characterised by the production of a second class of spores, the teleutospores. These are formed, as before, in sori, but the latter are black instead of being orange or yellow. In some of the rusts the teleutospores do not rupture the epidermis of the host-plant, while in others they do; but even when the epidermis ruptures the spores are not, as a rule, shed in the same manner as the uredospores. They remain attached to the straw until harvested. In appearance they are quite different to the uredospores, for they are bicellular, with a much thickened wall, unprovided with spines. Their function is, in fact, altogether unlike that of the uredospores, for they are not at all suited for wind-dissemination. They are resting spores, incapable of germinating, in most cases, for some time after their formation, even sometimes for many months. It appears, therefore, that the teleutospores are intended, naturally, to carry on the life of the species in the interval

between successive crops of the host-plant; especially since they are the last of the rust elements to appear, coming out often up to harvest time. We will see, however, that it is doubtful how far they fulfil this function, and in India there seems to be particular reason to suspect that there is something still wanting to explain their utility.

16. Each species of rust has its own period of quiescence for the teleutospore. During this time it has, perhaps, lain on the field, or been ploughed in, or has been harvested and fed to cattle and returned again to the field in the form of manure. All these vicissitudes it can apparently undergo while keeping its power of germination unimpaired, at least as far as experience in other countries goes. Having accomplished its period of rest it germinates in the presence of moisture, putting out a filament through a pore; unlike the uredospore this filament quickly ceases its growth on having attained a definite size. It does not form a mycelium, but, as the germ-filamant represents one, it is known as a "pro-mycelium," and its formation indicates the third stage in the life-history of the rust fungus.

17. The promycelial stage is short. As soon as the filament ceases to grow it divides up into segments, from each of which a minute stalk grows out laterally. On this a small ovoid spore is formed, quite colourless, and loosely attached on the stalk, so that it falls off readily and can be disseminated by the wind. The next stage, that resulting from the germination of the promycelial spores, or "sporidia" as they are termed, requires, in the case of the rusts under consideration, to be passed on a new host-plant (termed the "intermediate host"), but is in some cases entirely unknown and very probably absent.

Sporidia.

18. The connection between the black rust of cereals, **Puccinia graminis**, and the barberry plant has long been known. As far back as 1816, the yellow "cluster cups" of barberry rust had been shown to be connected with the rust of rye by a Danish schoolmaster named Schœler. His experiments were rough and remained unaccepted untill 1864-65 when they were confirmed by **de Bary**, who produced barberry rust from wheat, and rye rust from barberry, under conditions of scientific accuracy. He made the remarkable discovery that when sporidia from a germinating teleutospore are sown on wheat they die, whereas if sown on the barberry leaf they germinate by putting out a fine filament which penetrates the leaf across the cell walls of the epidermis. The filament then grows and branches, forming a mycelium, and in ten days or a fortnight begins to collect into masses under the leaf-epidermis and again proceeds to form spores. This period of the life of the rust fungus, passed, in the case of the black rust of cereals, on the barberry, constitutes the fourth stage of its life-history.

Puccinia graminis, and its connection with barberry.

The barberry rust.

19. The æcidial stage, so called from the production of æcidiospores on the intermediate host, was formerly considered to be a distinct fungus and called **Æcidium**. In the barberry its structure and life are shortly as follows. Where the leaf has become infected by a sporidium from the teleutospores of black wheat-rust, it becomes thickened through a cellular hypertrophy so as to form a cushion-like swelling, on which are produced two different sorts of spores. The first of these, in chronological sequence, appears as tiny bodies of unknown significance termed spermatia, produced in vast numbers in small cup-like receptacles, the spermagonia, on the upper surface of the leaf. They need not be taken into account further than to remark that, though they have been seen once or twice to germinate like the other spores by sending out a filament, and in other cases to multiply like a yeast-cell, their subsequent fate and function is quite unknown.

Spermatia.

20. A few days after the first appearance of the spermagonia the under-surface of the swollen areas begins to produce a second form of receptacle, of a golden-yellow colour, the well-known "cluster-cups." These are formed at first beneath the epidermis which they then rupture, turning back the edges and protruding the margin of a membranous-like receptacle, the pseudoperidium, which forms the sides and rim of the cup. Within this envelope the spores are produced. They are almost exactly like the uredospores, except that they are of a more golden-yellow colour and are often angular from pressure. They are disseminated by the wind, and germinate on falling into water by putting out a germ-filament, which, de Bary discovered, can carry the fungus back to the tissues of the wheat plant in the stage with which we started in describing its complicated life-history. It has been found that the germ-filament of the æcidiospore dies unless it be formed on the surface of one of the cereals liable to black rust, such as a wheat plant, when it continues to grow, enters the plant through one of the stomata, and gives rise to a mycelium capable of producing uredospores and teleutospores on the wheat.

Æcidiospores.

21. Were this cycle always to be carried out in its entirety, it is evident that the presence of barberry in the infected areas would be necessary for the recurrence of the disease. But it has long been known that the æcidial stage can be dispensed with, for a time at least, though until quite recently the general opinion appears to have been that a passage through the intermediate host was occasionally necessary. Even this, however, would mean that the barberry should exist in the neighbourhood of the wheat fields, and that its total eradication should lead to the disappearance of this particular rust. But practical experience has shown that neither of these is the case. Moreover, black rust commonly occurs, even in Europe, many miles away from the nearest barberry, and is prevalent in Victoria, Australia,

The barberry stage not essential.

where wild barberry is unknown and cultivated examples are rare. Dr. Cobb wrote in 1892, that up to that time the barberry **Æcidium** had never been seen in Australia. Yet rust had existed probably for years before this. In India the barberry is found only in the hills, hundreds of miles from some of the areas in the plains where rust is most severe and where **Puccinia graminis** has been found to be one of the causes of it. Not alone is it impossible in these cases for the barberry to play any part, but Eriksson has shown that the radius of infection in ordinary cases is not above 25 yards around the bush, and that hence the *rôle* of wind-borne æcidiospores from the barberry in connection with the disease has been immensely exaggerated. Besides, it is at least questionable if the true barberry **Æcidium** belonging to the black wheat rust fungus occurs at all in the Himalayas. Barclay has described an **Æcidium** whose measurements correspond fairly closely with those of the common one, from Simla, and Massee considered a specimen from Jaunsar was identical with it. In neither case was the experiment of obtaining rust on wheat from the fungus tried. I have found that the common **Æcidium** on barberry at Mussoorie is not allied to the wheat fungus, but is a distinct and remarkable species, accompanied by a uredo-form on the barberry itself and giving rise to witch's brooms on the attacked bushes. The barberry may be entirely left out of account in India.

Other rusts.

22. The case with regard to the other rusts is quite parallel. Two of these are known on wheat in Europe, besides those which occur on other cereals but do not attack wheat. They are named **Puccinia glumarum** and **Puccinia triticina.** In neither case is an æcidial stage or an intermediate host known. If such exist they have not yet been discovered, and taking into account the minuteness of the search their existence is at least problematical. In Australia **Puccinia triticina** occurs with **Puccinia graminis** and here also an æcidial stage has not been forthcoming. This fungus was long confounded with the brown rust of rye, **Puccinia dispersa,** for which certain Borragineæ serve as intermediate hosts. Eriksson has, however, shown that the æcidiospores from these do not possess the power of infecting wheat.

No æcidial stage.

23. Hence, so far as the three above-mentioned rusts of wheat are concerned, the presence of any intermediate hosts can no longer be considered a necessary factor in their cycle; for even if other intermediate hosts exist, and remain yet to be discovered, it is quite certain that their presence is not essential, and that the disease can recur year after year without their intervention.

Reappearance of the disease.

24. To explain how, in the absence of an intermediate host, the fungus reappears each year, the following possibilities exist: 1. The

rust, whether **Puccinia graminis, Puccinia glumarum,** or **Puccinia triticina,** may, it has been suggested, arise from infection by uredospores communicated to the wheat from other species of grasses. It is known, for instance, that **Puccinia graminis** exists on a number of grasses in the uredo-teleuto form. But on none of these has it been found capable of readily infecting wheat. The same may be said of the other wheat rusts, for even when they are found on other host-plants (called "collateral hosts"), their uredospores cannot be induced to infect wheat, except under extremely favourable conditions in a few instances. The wheat rusts are, in fact, highly specialized parasites, in the sense that they form "races," each race being restricted to one or a few allied host-plants. It would take far too long to go into the evidence on this question, but there is none in connection with rust which stands so clearly answered as this of the inadequacy of collateral transmission to account for the disease. In the same line of reasoning it has been thought that stray wheat plants, self-sown, "volunteer" wheat, may serve to carry over the germs of infection. But such an explanation, possible as it is in some localities, is quite out of the question in Northern Europe, where snow covers the ground for some months; and is still more futile in India, where the intense heat of the plains burns up every blade of grass in the hot season, and "volunteer" wheat is unknown.

Uredo-teleuto form found on other grasses.

But spores do not infect wheat.

Volunteer wheat.

25. 2. Or it is possible, as has been suggested in Australia and elsewhere, that, owing to the scarcity of an intermediate host in a particular area, the sporidia resulting from the germinating teleutospores have developed a power of infecting wheat directly; so that when the teleutospores germinate after their rest, as they do usually about the time of the appearance of the new crop, they infect the growing wheat. Developing then within the host, they, after a prolonged incubation period, come to the surface to form uredo and teleuto sori. But though it is too much to say that this possibility has been definitely disproved, still there is a large body of experiment and observation tending against its acceptance. The result of numerous attempts to get germinating sporidia to penetrate into the wheat tissues has been, on the whole, negative. Similarly, experiments to cause infection by growing wheat in germ-tight cases, with the seed surrounded with fragments of straw bearing ripe teleutospores, have also failed. The most rigid microscopical examination of the young growing plant has yielded no trace of the fungus within the growing axis, even when rust has afterwards proved to be extremely severe in the fields from which the specimens were taken. The mycelium of the rust within the plant can only be detected quite a short time before the sori become visible on the surface. In India attempts to germinate the teleutospores at all,

Sporidia may infect wheat.

Not proven.

after they had been preserved over during the hot season and rains, made by Mr. Hayman, Deputy Director of Agriculture, United Provinces, (see Report of the Cawnpore Experimental Farm, 1902), and also by myself, have been unsuccessful so far. The probabilities then are all against this view.

Failure to germinate teleutospores in India.

26. 3. It has been suggested that the uredospores themselves, instead of being blown away and germinating at once, can survive until the next growing season and then infect the wheat. There is even less possibility of this being the correct solution than of the last. The incubation period, between the moment of infection by the uredospore and the appearance on the surface of the resulting sori, is about ten days. But rust, in Sweden at least, does not appear usually for about two and a half months after the date when the uredospores from last season must germinate, if any really possess this power. For if any germinate at all, some will surely do so as soon as the conditions of temperature and moisture become favourable after the winter. In the same way in India germination should be expected in November or December at latest, whereas, at Cawnpore, rust does not usually appear before the middle of January. Besides uredospores capable of germinating in the next season have never been found, except in mild climates. They do not occur in Sweden and probably not in India.

Uredospores may infect the new crop.

But very unlikely.

27. 4. There remains a possibility, suggested years ago, but only recently brought prominently forward by the work of Eriksson, that the disease is hereditary in the strictest sense of the word, and passes from generation to generation in the seed. This view, which has given rise to an animated controversy, is based on a number of theoretical considerations, and supported by a mass of minute observations made by Eriksson over some ten or twelve years. It is impossible to give the arguments in a short space, so that it must suffice to say that, while the theory has not met with anything like universal acceptance, it is certainly the most plausible explanation as yet offered. The great difficulty is that, as above mentioned, no trace of the fungus can be found in the young growing plant, and that the seed similarly shows no modification capable of being detected by the means at present at our disposal. To surmount this, Eriksson has supposed the existence of a germ in a plasmatic state intermingled with the plasma of the cells of the host, but incapable of visual detection. This "mycoplasm" can pass on from generation to generation by seed infection from within the parent plant, until something occurs by which it is induced to come to the surface. What this something is cannot be said with certainty, but favourable external conditions, such as moisture, and heat and certain conditions of age, etc., of the host-plant appear to be the chief.

Eriksson's theory.

28. It is only at a stage immediately prior to the outbreak of the pustules that there is any positive evidence of the existence of such

a germ as Eriksson suggests. Shortly before the appearance of the sori he has detected peculiar corpuscles in the wheat cells which he considers to be an intermediate stage between the mycoplasmatic and the mycelial condition, for he claims to have seen them develop into the threads of the parasite between the cell walls so as to form a mycelium. Hence instead of the fungus mycelium having been developed in every case from the germination of a spore on the outside of the epidermis of the wheat plant, and its subsequent penetration within the tissues, Eriksson holds that it frequently arises from within, irrespective of any external infection. He does not deny that the latter occurs also, but he considers that it is not so active as is usually believed and is quite insufficient to explain the first sudden outburst of the disease so familiar to all who have witnessed the incidence of a severe attack of it. External infection by uredospores serves to spread the fungus around the first opened sori and to multiply its effects, but cannot explain its first appearance nor the manner in which the disease persists from year to year.

The problem in India.

29. If now we apply the above considerations to the problem as it presents itself in India, we can see where our knowledge of the life-history of the cause of the disease is deficient and to what points to direct our attention.

30. First: it is certain that the black rust caused by **Puccina graminis** passes to the barberry and can be carried over on the latter plant until the new crop is ripe for infection. But this method while accounting for only one of the several wheat rusts which occur (and that not at all the worst), does not account even for this except in a comparatively small number of cases, and certainly not so far as India and Australia are concerned.

31. Second: it is still possible, though unlikely, that the spores, whether uredospores or teleutospores, can retain their vitality until the following season and on germination infect the young wheat. But this is not supported by the results of experiments, and is besides opposed to the phenomena presented by the first attack of rust each year.

32. Third : it is possible, especially so in India where rusts have not been the subject of prolonged study, that other plants exist which may play a part in one or other of the Indian rusts, similar to that played in Europe and America by the barberry in black rust. This possibility requires special consideration in this country from the fact that Doctors Cunningham and Prain considered it probable that such a plant exists, and is to be found in a weed **Launea asplenifolia** (often called in the vernacular "jungli gobi"), which they held there was reason to believe formed the "intermediate host" for one of our wheat rusts. In an exhaustive tour in Upper Bengal, Central India, the Panjab, Rajputana, and the United Provinces, the authors found that **Launea** occurred almost everywhere it was looked for. Everywhere it suffered from the attacks

Launea.

of a Uredine whose uredospores could not be distinguished from those of the wheat rust in question. All stages occurred on the **Launea**, the æcidia being produced on peculiarly modified shoots. To accept this plant as either an "intermediate" or a "collateral" host for one of the wheat rusts, it is necessary that rust should be produced on wheat by sowing on it either æcidiospores or uredospores from the **Launea**, under conditions which permit one to exclude all other germs. This has not been done, but forms one of the points at present under investigation at the Cawnpore Government Farm, by **Mr. Hayman** and myself. Other similar plants may, perhaps, exist and may be brought to light by anyone possessed of powers of observation and a certain degree of patience. We cannot, in fact, have too much assistance in this aspect of the question. The wheat fields are surrounded by many plants bearing rust. Linseed, common *dub* grass (**Cynodon Dactylon**), *Motha* (**Cyperus**), *takri* (**Paspalum sanguinale**), several of the Andropogons (vern. *palwan*, etc.), **Asphodelus**, even trees like the *Sheisham* (**Dalbergia sissoo**), are commonly rusted, and a complete list of the rusts which occur within the wheat areas would certainly exceed a hundred species. They are not difficult to detect. Moist places and the cold season are the most favourable time and place, but there are many exceptions. Once the eye has become habituated to their appearance by the examination, closely, of some one species, they can be quickly recognised. All these rusts may fail to account for the wheat rust. For the rusts on other plants may either be found to be infected by specifically different rust-fungi (as in the case of those mentioned above), or, where the rust is indistinguishable from that of wheat, it may yet be incapable of passing to the wheat. Observation and experiment alone can decide this, and the procuring of a complete list of the rusts occurring in the vicinity of the wheat fields is one of the first needs in the local investigation of the rust problem. It is not a work that can quickly be accomplished by one person, but if in every province a few zealous collectors were to assist, it would be shorn of half its difficulties.

Other plant rusts.

33. When all these rusts have been submitted to examination and, in the case of those outwardly identical with the wheat fungi, their power of passing from the collateral host to the wheat tested experimentally, the first great step in determining where the origin of the mischief is to be sought will be taken.

34. Only two other grasses have so far proved, in India, to be attacked by fungi specifically identical with those of the cereals, *viz.*, **Festuca gigantea**, found by Barclay, attacked by **Puccinia graminis**, and **Phalaris minor**, which I obtained bearing the Indian form of **Puccinia glumarum** at Hissar. **Berberis aristata** and **vulgaris** also bear the æcidia of **Puccinia graminis** in the Himalayas, according to **Barclay and Massee.**

Wheat rusts on other Plants.

35. Fourth: it is, of course, possible that when all the rust-bearing plants of the plains have been investigated, they will still throw no light on the problem of the persistence of wheat rusts from season to season. This has been the case elsewhere. There then remains to be considered the theory of Eriksson of the seed-borne germ, the experimental test of which is a matter of great difficulty. It requires work carried on over several seasons under conditions which approximate to those of the field, but which permit of the exclusion of foreign germs. The preliminaries of this have already been commenced at Cawnpore Farm.

The Varieties of Rust in India.

36. It is not possible, at present, to give accurately either the number or the identity of the Indian cereal rusts. In India, as elsewhere, it used to be supposed that there were two principal ones, **Puccinia graminis** and **Puccinia rubigo-vera.** It is now known that this last form comprised a number of distinct species which had been confused with one another by the earlier observers. The work of Doctors Cunningham and Prain, above mentioned, proved that there were several distinct rusts in the country. Three of these appear, from the investigations of 1896 and 1903, to be quite common. Two of them are, perhaps, equivalent to two of the well-known European ones, while the third is in many respects peculiar. In the note of 1896, Doctors Cunningham and Prain described four wheat-rusts and two of barley, one of which they considered identical with one of those of wheat. They were not named scientifically, the authors contenting themselves with indicating their characters and relationships and leaving to the future to decide their similarity to those of other countries; at the same time inclining to the opinion that they were, in some cases at least, quite distinct from any of these.

Several distinct cereal rusts.

37. Though there are certain differences between the Indian and European types, still I think we may conclude that **Puccinia graminis** and **Puccinia glumarum** are both present in India. The former occurs on wheat, barley and rye, the latter on wheat and barley only. There are, in addition, two other rusts on wheat, one of which is common and the other rare, having only once been seen. It is perhaps an aberrant form of one of the others. So far as it goes, then the following list of the cereal rusts is complete. It modifies the conclusions of Doctors Cunningham and Prain chiefly in uniting the "Ferozepore" wheat rust and "Mogul Serai" barley rust of these authors together as **Puccinia glumarum,** there being now abundant evidence that they are identical; and in giving the European names to the first two of the list, since the differences do not appear to be sufficient to separate them as distinct species.

Puccinia graminis and Puccinia glumarum occur in India

List of Indian cereal rusts.

38. 1. **Puccinia graminis** *Pers.*, occurring on wheat (form spec. **Tritici**), and on rye and barley (form spec. **Secalis**). It is probable, from analogy, though not yet experimentally demonstrated in India, that the two forms are physiologically distinct and each incapable of infecting the host-plants of the other, except under very favourable conditions.

39. 2. **Puccinia, glumarum** *Eriks.* and *Henn.*, occurring on wheat (form sp. **Tritici**), and barley (form sp. **Hordei**), both forms being probably physiologically distinct.

40. 3. A rust (**Uredo**) described by **Doctors Cunningham** and **Prain** under the name of Shibpur rust, and found again this year at Cawnpore by **Mr. Hayman** and myself. We have provisionally spoken of it as Orange rust from the colour of the **Uredo** pustules. It is remarkable in possessing no teleutospores on wheat, at least none have been found after a somewhat thorough search. It is, when prevalent, a serious enemy, even according to **Dr. Prain**, the worst to which the crop is liable ("Rust in wheat in the Australian Colonies"). I have seen it only on wheat.

41. 4. A rust found by **Doctors Cunningham** and **Prain** at Saharanpur on a single plant. It appears to be distinct from any of the above.

No rust on oats.

42. No rust has as yet been found on oats in India.

43. To give a more detailed account of the above rusts, so as to admit of their recognition with the naked eye, is far from easy. For they are extremely variable, and the appearance of a plant just showing the earliest attacks, and of one far advanced in a severe outbreak, may be totally different.

Puccinia graminis detailed description.

44. **Puccinia graminis** is usually, so far as my experience goes, of late appearance. It is also, though the most formidable outwardly from the manner in which it scars and ruptures the attacked tissues, the least damaging to the grain. The evidence of **Dr. Barclay**, **Doctors Cunningham** and **Prain** and **Mr. Hayman**, agree in this.

Uredospores.

45. The uredospores are borne in elongated sori of a warm brown colour, which often become blackish later on from the development of teleutospores in the bed of the sorus amongst the uredospores. The sori are often a quarter of an inch or more in length, and I have found, where many run together, that a total length of several inches may be attained. The elongation is, as in most Uredineæ, in a direction parallel to the axis of the organ on which the fungus is situated. Coalescence laterally is common. The sori are found on the culms, leaf-sheaths and leaves; in severe cases on the glumes and awns as well. The relative degree to which each of these parts may be affected varies with the degree of severity of the attack, but in general it may be said that the culm and leaf-

sheath are the most favoured positions. The uredospores are elongated, oval or ovate, measuring 25 to 30 by 17 to 20 thousands of a millimetre in diameter. The pores are arranged equatorially and are usually four in number, but sometimes more. This rust in Europe is variously stated to have two or four pores, while Cobb gives four as the number for Australia. Germination occurs readily in water, and I have obtained it freely several weeks after the spores were formed.

Teleuto-spores.

46. From the same mycelium, and often in exactly the same spot as the uredospores, the teleutospores appear at a later date. Their sori resemble those of the former in rupturing longitudinally, but they are black. The teleutospores are 40 to 60 by 15 to 20 thousands of a millimetre in diameter.

Further history.

47. The further history of this rust in India is unknown. As mentioned above, the teleutospore has not, as yet, been got to germinate here, and the barberry on which the æcidial stage appears does not occur on the plains. It is possible that there is no further history, that uredo-teleuto stage succeeds to uredo-teleuto stage without intermission season after season; or it is possible that another intermediate host than the barberry remains awaiting discovery, an event which would lead us to question the identification of this rust with **Puccinia graminis.**

48. On barley the rust is the same in its general characters.

Puccinia glumarum: detailed description.

49. **Puccinia glumarum** is usually of earlier appearance than **Puccinia graminis**, and, as far as experience goes in India, is much more destructive to the grain.

50. The uredo-sori are of a pale yellow or lemon colour. They are formed chiefly on the upper surface of the leaves in mild cases, and on both surfaces of the leaves, on the leaf-sheaths, culms, glumes, and awns in severe. The under-surface of the leaf is never so closely covered with the sori as the upper. In a mild attack, such as that seen at Cawnpore this year, the first sign of the disease is the disappearance of the green colour of the leaf in longitudinal streaks. This occurs on the last formed leaf as well as on the radical leaves, and near the leaf tip as well as near the base. It is followed very quickly by the development of the sori, as yellow pustules occupying the centre of the discoloured area, in one or more rows. Each row consists of a series of sori arranged end to end with the most perfect regularity, each being quite distinct from that above and below. The sori are small, shortly oval, and remain covered by the unbroken epidermis for a considerable time. Now this appearance is totally distinct from that which is found when a severe outbreak occurs. In the latter case the discoloured areas do not appear in streaks but cover large patches of the leaf, and the pustules come out in such quantities that the linear arrangement is lost or obscured, and the whole leaf appears to be covered with densely crowded yellow spots over both

surfaces. Spores are shed from the sori in such numbers as to form a distinctly visible layer on the ground. They are spherical or shortly oval, and measure 23 to 35 by 19·5 to 35 thousands of a millimetre in diameter. They have six or more pores, which, when six, are often arranged in two bands of three, midway between the equator and the poles. Uredospores.

51. The next stage is the development of teleuto-sori, which appear as black patches or spots, chiefly on the under-surface of the leaves, but also on all the other parts of the plant above ground. Sometimes these are arranged, especially on the sheaths and culms, in distinct linear series, but often they form more or less irregular patches of a horny consistence. The epidermis is not ruptured, and the appearance of flat black crusts is quite different from the raised gaping black wounds of the teleuto-sori of **Puccinia graminis.** The teleuto-spores measure 35 to 63 by 12 to 20 thousands of a millimetre, the breadth being measured at the septum. The rust differs in one respect from the corresponding European one. In the latter the teleutospore beds are surrounded by "paraphyses," sterile club-shaped bodies developed from the fungus mycelium. In the Indian form my experience agrees with that of Dr. Barclay and Mr. Hayman that these are not formed. This, no doubt, is a serious difficulty in identifying the latter with **Puccinia glumarum**, but not, in my opinion, sufficient to separate them specifically. An actual comparison with the European form will be necessary, however, if it be found that this character is constant, particularly to determine if paraphyses are always formed in Europe. I have failed to trace Eriksson's reference that Loverdo has recorded an absence of them on one occasion.* Teleutospores. Absence of paraphyses in India.

52. The third and fourth rusts mentioned above call for little remark at present, for they are imperfectly known. In both of them the **Uredo** form has alone been found. In the "Shibpur" or "Orange" rust the sori are round or very shortly oval, and are irregularly scattered over the upper surface of the leaf, being very rarely found elsewhere. The spores correspond, so far as my measurements show, exactly to those of **Puccinia glumarum,** but the sori are of a distinctly warmer yellow or orange colour. There is no question that this is a distinct form, of early appearance and destructive; but regarding the area of its distribution and its life-history it is premature to speak. It is this rust for which Doctors Cunningham and Prain suspect **Launea asplenifolia** acts as an intermediate host. This view has not so far been confirmed. The rust of which a single specimen was obtained at Saharanpur by Doctors Cunningham and Prain is also very imperfectly known. The sori are very large and "Shibpur" or "Orange" rust. Possibly connected with Launea.

* Since writing the above, paraphyses have been found in specimens from Hissar. (*Note added while going to press.*)

elongated, and the uredospores measure 23·2 by 17 thousands of a millimeter in diameter (probably more when fresh), and have 9 to 13 conspicuous germ-pores. I have not seen this rust.

The Need for Meteorological Observations.

53. Next to the study of the other rust-bearing plants of the wheat districts, in the search for possible intermediate or collateral hosts for the wheat rusts, the most important observations that can be made are those on the influence of the weather on the disease. That there is a connection has long been known; but that it is more complex than was once supposed is at least possible. As long as it had been believed that infection of the wheat took place from without, by means of æcidiospores from an intermediate host or uredospores from a collateral one, the influence of temperature, moisture, storm, etc., was easy to understand. A high wind tends to blow the spores to a distance, a suitable temperature and excessive moisture assists germination and enables the germ tube to enter the host-plant. It is possible that this is still a sufficient explanation as it is in the case of the potato blight, where external conditions play a very large part. But the development of Eriksson's mycoplasma theory, and the arguments brought forward by him in support of it, have naturally led to doubts. It is stated that the spores do not by any means admit of being borne to a considerable distance by the wind. That in the case of the barberry æcidiospores, for instance, 25 yards is about as far as they are able to infect. Also that the uredospores in several cases, as for instance, in **Puccinia glumarum**, do not germinate as freely as might be expected when they have fallen on the leaves of the healthy plants, but that it is sometimes almost impossible to find a germinated spore on searching the leaves, even when the climatic conditions have been nearly ideal for germination. Instead, then, of the conditions, on which it depends whether a severe or a mild attack of rust is to take place, being those which influence germination, it is possible that we must look deeper, and find out what it is that induces an internal germ to come to the surface. Such an influence may be exercised at any time during the growth of the infected plant, for it may act by disturbing the balance which exists between the mycoplasma and the plant in which it lives. Certain conditions, such as excessive moisture or warm weather, may give an impulse to the fungus which enables it to overcome the resistance of the host-plant. The balance once upset, the fungus may continue to gain way and eventually break to the surface, perhaps after a considerable time has elapsed from the period when the mischief was done. Rain in April, Eriksson considers, predisposes to an outbreak of **Puccinia glumarum** in Sweden, the rust often not being visible before June or July.

Influence of the weather.

Bearing on Eriksson's theory.

Need for careful notes.

54. Hence to obtain data worth having it is necessary to keep diary notes, not perhaps day by day, but at least twice a week from the time when the wheat is, say, two months old, until the appearance of rust. The conditions to be noted are rain, cloud, wind and mean temperature, and the records must be kept for several years in a particular locality before conclusions can be drawn. If this were done in some eight or ten Government farms, or other suitable localities, for a period of five years, we should be in possession of a mass of facts which might yield valuable results.

The Means of Combating Rust.

Treatment.

55. In the absence of extact knowledge of the origin of the disease, remedial measures could not be expected to have obtained a considerable decree of success. As a matter of fact they are confined practically, at the present moment, to providing sorts of wheat little liable to the disease. This method has been remarkably successful in Australia, but its adoption is attended with a good deal of difficulty. It is not always easy to persuade the farmer to grow a variety on the chance that it will be a bad rust year, and that the variety is likely to suffer less than the others. At the same time it is the only method to be recommended at the present day, and it is certainly capable of great developments and of saving an enormous sum of money annually lost from the disease. As our knowledge increases, it is not unlikely that some of the simpler methods now discredited, such as seed treatment, or manuring, may be modified so as to become effectual in checking the disease. But it is evident that nothing much can be done as long as the all-important question, from a practical point of view, of the origin of the disease, remains unanswered, at least in a manner to force acceptance.

Practically confined to obtaining rust-resisting wheats.

56. Professor Eriksson, to whom, whether his final theory will stand the test of time or not, we still owe more of our knowledge than to any other single worker, gives as a result of his long experience the following suggestions for the organisation of future investigations :—

Eriksson's recommendations for future work.

"1. In every country where the rust of cereals is of great practical importance a special experiment station should be established to conduct investigations on the rust of cereals. At this station field experiments with the varieties of cereals cultivated in the country should be organised to test their resistance to the different forms of rust appearing in the country.

An experimental farm.

"2. According as information is acquired, by trials carried on continuously for at least five years, regarding the qualities of the different varieties of cereals and the different forms of rust found in the country it will be possible—

To choose the better varieties.

(*a*) to cease to cultivate the varieties which by these trials have been shown to be very liable to one or other of the

more dangerous forms of rust, and to choose amongst the other varieties those which have displayed a sufficient resistance to cold, which have ripened early, which have yielded freely, and which have united these qualities to others of value;

To investigate conditions of soil, manure, etc.

(*b*) to determine by research, formulated and carried out on a systematic plan, in what degree the external conditions of soil, situation, manure, season, etc., are capable of influencing the rusting of the future crop—for these trials varieties which have been found very liable to one or other form of rust should be chosen; and

To improve the races.

(*c*) to endeavour by rational cultivation, by improvements and by crossing certain sorts which have shown valuable qualities, to obtain races which from every point of view can be considered as the most advantageous for the country.

To meet for discussion.

"3. Finally—the question of the rust of cereals being of the greatest practical importance for every country—means should be furnished to those in whose hands the direction of these investigations are placed, to meet from time to time, that is to say, at least every five years, in order to discuss, according as experience is gained, the value of any new observations and to gain for their work the advantage of being based on a plan common in its essentials to all."

G. I. C. P. O.—No. 1208 R. & A.—21-11-1903.—200.—C. M. W.